American Society of
Agricultural and Biological Engineers

Infiltration Rates on Abandoned Road-Stream Crossings

Randy B. Foltz , Research Engineer

USDA Forest Service, Rocky Mountain Research Station, , 1221 S. Main St, Moscow, ID 83843,

Emilie Maillard , Student

Ecole Nationale d'Ingénieurs des Techniques Agricoles de Bordeaux, 1 Cours du General de Gaulle, BP 201, 33175 Gradignan cedex, , FRANCE

This is not a peer-reviewed article.

Paper No: 035009
An ASAE Meeting Presentation

Written for presentation at the

2003 ASAE Annual International Meeting
Sponsored by ASAE
Riviera Hotel and Convention Center
Las Vegas, Nevada, USA
27- 30 July 2003

Abstract. Road obliteration, the process of removing culverts, restoring stream gradient, and recountouring the road to match the hillside, is one of the tools to deal with excess forest roads. After road obliteration former stream crossings are locations where sediment travel distances to the aquatic environment are short. A study to determine the infiltration characteristics and raindrop splash characteristics found that infiltration was approximately 10 mm/h for former roads that had been obliterated for 2 to 3 years. This value was less than typical forest floor values of 80 mm/h, but greater than road ones of 2 mm/h. Raindrop splash coefficients of 2.5 x

10^{6} kg s / m^{4} were closer to road than to forest floor conditions. Even though the increase in infiltration was modest, an improvement from 2 to 10 mm/hr, results of WEPP model predictions of runoff events from 30-years of simulated climate indicated a large reduction in the number of runoff events from both rainfall as well as snowmelt events.

Keywords. Road obliteration, road abandonment, hydraulic conductivity, interrill erosion, raindrop splash.

Introduction

Many United States Forest Service roads were built in order to allow the forest managers to accomplish the tasks of timber harvesting and forest management. In 2000, the inventoried road length was 623,000 kilometers. An estimate in 1998 was that allocated funds were able to maintain about 40% of this road system (Coghlan and Sowa, 1998). The remaining road miles receive little or no maintenance. Un-maintained roads can present environmental problems from chronic surface erosion to episodic mass wasting events.

One solution to this under-funding situation is to prioritize roads based on long-term road needs, maintenance requirements, and environmental liability then to remove those with a high ranking. Since 1998 the US Forest Service reports having decommissioned 23,700 kilometers of forest roads (Bosworth, 2003). A variety of terms have been used for the process of road removal including abandonment, decommissioning, and obliteration. In this paper road obliteration will mean making the landscape look like the road was never there. The process usually involves removing culverts and reshaping the ground surface to the original contour. Fill material from the road prism is pulled onto the running surface and shaped to match the hillside contour. Fill materials are removed by heavy machinery similar to that used to build the road. The culverts are removed and the stream channel reestablished through the former road prism to match the original stream gradient. Ground cover in the form of transplanted bushes or branches from nearby vegetation and seeding of grasses and forbs are often applied to the bare soil. Vegetation becomes reestablished on the bare soil.

Although the intent of the obliteration is to make the former road look like it was never there, it does not immediately return to its pre-disturbance hydrologic function. Because former stream-road crossings are adjacent to the stream, eroded sediment has to travel only a short distance to enter the aquatic system.

Several studies have been performed to determine the infiltration characteristics of both road surfaces and forest floors (Ward, 1983; Luce and Cundy, 1994; Robichaud, 1996). This information allows the prediction of the amount of runoff that can be expected from precipitation events. Infiltration rates for obliterated roads are not widely known. A study was undertaken by the Rocky Mountain Research Station of the US Forest Service to fill this knowledge gap.

The objective of the study was to determine infiltration rates at former road crossings at selected sites in the Pacific Northwest. In addition to the infiltration rates, erosion due to raindrop splash was to be measured.

Methodology

Rainfall simulation on one meter square bordered plots was used to determine infiltration and rain drop splash parameters. The rainfall simulator used a Spraying Systems Veejet 80100 nozzle to approximate the raindrop distribution of natural rainfall. The simulator was built so that it could be carried into sites not accessible by vehicle. Fiberglass and carbon fiber cloth was used in the construction resulting in a weight of 13 kg. A set of three fiberglass legs held the simulator 3 meters above the plots so that the drops could attain terminal velocity. A water pump weighing 5 kg and a generator of 14 kg completed the rainfall simulator. A three person crew can carry the simulator and associated equipment in a single trip to the site.

Once the legs and a wind screen are attached to the simulator housing, it can be centered over the plot by three people. Each leg is adjustable so that slopes up to 100% can be accommodated. Attaching the pump discharge, the motor controller, and staking a wind screen completes set up of the simulator. Because the simulation was performed at a stream crossing, water from the stream was used. An experienced crew can erect the simulator and be ready to begin simulation on a previously prepared plot in an hour.

Rainfall simulation plots on the lower third of the former stream crossing were selected. The upper border and the two side borders were 16 gauge sheet metal driven into the soil to a depth of 50 mm. The lower borders consisted of a runoff apron flush with the soil surface that drained into a collection trough with a centrally located 25 mm opening. The runoff apron was placed on top of a 6 mm thick layer of bentonite to prevent any water from flowing under the apron. To allow access for the 500 ml bottles, a small hole was dug in the soil. Dimensions of the exposed soil inside the plot was 1 m by 1 m.

Three rainstorms with an intensity of 89 mm/h with a duration of 30 minutes were applied to each plot. An initial simulated storm, called the dry run, was applied to the plot followed the next day by a second storm, called the wet run. The third storm, called the very wet run, was applied within 15 minutes after the end of the wet run. The plot was covered to prevent evaporation or natural rainfall from reaching the plot. Soil moisture samples from three depths, 0 to 40 mm, 40 to 80 mm, and 80 to 120 mm, were taken before and after each simulated storm. These soil samples were oven-dried overnight at 105C.

Once runoff began on a plot, timed grab samples in 500 ml bottles were taken each minute for the duration of runoff. These runoff samples were oven-dried overnight at 105C. Water runoff rates, sediment concentrations, and sediment flux rates were calculated based on these samples.

Ground cover was measured by placing a 10 by 10 grid over photographs of the plot. Counts of the number of points covering ground cover of any type were made. The counts were converted to percent ground cover.

Modeling

The Water Erosion Prediction Project (WEPP) model was chosen to determine the infiltration and erosion characteristics of the plots. The WEPP model (Flanagan and Livingston, 1995) is a physically based soil erosion model that provides estimates of runoff, infiltration, soil erosion and sediment yield considering the specific soil, climate, ground cover, and topographic conditions.

The WEPP model uses an implementation of the Green-Ampt Mein-Larson model for unsteady intermittent rainfall to represent infiltration (Stone, et al., 1995). The primary user defined parameter is hydraulic conductivity. Interpretation of this parameter is straightforward. Higher values indicate a more rapid rate of infiltration and, hence, less runoff. The parameter is also an indication of the maximum rainfall rate that a soil can absorb without producing runoff.

Raindrop splash in the WEPP model is characterized by an interrill erodibility coefficient which is a function of rainfall intensity and runoff rate (Alberts, et al., 1995). This coefficient can be varied by the user. Interpretation of the interrill erodibility coefficient is also straightforward, although the units of kg m / s^4 are not intuitive. Higher values indicate higher raindrop splash erosion. The odd units are a result of combining rainfall intensity units of length per time (L/T) and runoff rate units of L/T to yield sediment detachment with units of mass per length squared per time ($M/L^2/T$).

One of the features of the WEPP model is its ability to describe up to 10 combinations of soil and vegetation along a given hillslope. Each unique combination of soil and vegetation is referred to as an overland flow element (OFE).

The plot was represented by a single OFE. Measured values such as ground cover, soil moisture content, precipitation intensity and duration were used as inputs to the model. Hydraulic conductivity was determined by trial and error calibration of the WEPP model until the predicted runoff matched the observed runoff. Since the plots were too short, 1 m, to allow rill erosion, all of the observed erosion was assumed to be due to raindrop splash. WEPP model runs with varying values of the interrill erosion coefficient were performed until the predicted erosion matched the observed erosion.

To test if there was a statistical difference in hydraulic conductivity, values for each plot were combined for a plot level average for each site. A general linear model was used to test if there was a difference among the three treatments. Tukey’s multiple comparison procedure was selected for one-step pairwise multiple comparisons because it maintains Type I error protection. Identical statistical procedures were used to test the interrill erodibility coefficient for differences.

Results and Discussion

Field Observations

The study was performed on three sites near McCall, ID on the Payette National Forest. Each of the sites were located at obliterated road-stream crossings. All sites had the fill over the culvert and the culvert removed, hauled off site, and the stream banks returned to the original side slope. A scattering of woody debris was left on each site. Each site was treated with a seed mix, biosol, and straw mulch immediately after obliteration.

A site called Brush Creek was in a supalpine fir/pachistima habitat on a gravelly loamy sand soil derived from basalt parent material. The road was obliterated two years before the study. Two sites (Long Walk and Summit) were in a subalpine fir/huckleberry habitat on gravelly sand soil derived from glacial till parent material. The Long Walk and Summit sites had road obliteration work done three years before the study. The physical characteristics of the three sites are summarized in Table 1.

Table 1. Physical characteristics of the sites.

Site	Years Since Obliteration	Parent Material	Soil Classification	d_{50} (mm)	d_{84} (mm)	d_{16} (mm)
Brush Creek	2	Basalt	Gravelly loamy sand	0.20	1.32	0.04
Long Walk	3	Glacial Till	Gravelly sand	0.59	5.57	0.15
Summit	3	Glacial Till	Gravelly sand	0.46	2.53	0.11

Within each site there were three plots located in the exposed bank near the stream. The plots were chosen to be representative of the surface. Ground cover ranging from 26 to 54 percent consisted of grasses, forbs, and woody debris up to 200 mm diameter. The slope shape of each plot was linear with slopes of 9 to 26%. Table 2 presents these values for each plot.

Table 2. Physical characteristics of the plots.

Site	Plot	Slope (%)	Ground Cover (%)
Brush Creek	1	21	42
	2	25	44
	3	20	30
Long Walk	1	26	38
	2	20	43
	3	10	26
Summit	1	9	54
	2	16	44
	3	15	48

Field Observations

The runoff and sediment production from the three plots were averaged for each site and are shown in Table 3. Runoff values ranged from 28.9 to 34.3 mm which was approximately 1/3 of the applied rainfall. All three of the sites had increasing runoff volume with subsequent events indicative of the soil profile becoming increasingly saturated. Sediment production ranged from 190.4 to 741.8 g/m ^{2} . Two of the three (Brush Creek and Long Walk) had the highest sediment production on the initial event indicative of a decreasing sediment supply.

Table 3. Average runoff and average sediment production for each site and run.

Site	Run	Runoff Depth (mm)	Sediment Production (g/m ^{2})
Brush Creek	Dry	27.3	231
	Wet	31.4	190
	Very wet	34.3	195
Long Walk	Dry	23.6	742
	Wet	30.1	643
	Very wet	30.9	593
Summit	Dry	28.9	269
	Wet	30.6	279
	Very wet	31.0	257

Modeling Results

The WEPP model was used to determine the hydraulic conductivity and the interrill erosion coefficient for each of the sites (Table 4). The basalt site (Brush Creek) with a d_{50} of 0.20 mm had the lowest hydraulic conductivity of 7.7 mm/h. The two glacial till sites with d_{50} of 0.46 and 0.59 had hydraulic conductivity values of 10.1 and 13.1 mm/h, respectively. Interrill erosion coefficient values were lowest at 1.1 x 10 ^{6} on the Brush Creek site and highest on the Long Walk site at 4.0 x 10 ^{6} kg s / m ^{4} . The other glacial till site, Summit, had an intermediate value of 2.3 x 10 ^{6} kg s / m ^{4} .

Table 4. Hydraulic conductivity and interrill erosion coefficient.

Site	Hydraulic Conductivity (mm/h)	Interrill Erosion Coefficient (kg s / m ^{4})
Brush Creek	7.7	1.1 x 10 ^{6}
Long Walk	13.1	4.0 x 10 ^{6}
Summit	10.1	2.3 x 10 ^{6}

The overall analysis of variance F-test for differences in hydraulic conductivity was $F_{2,6}$ equal to 4.32 (p-value of 0.069) This means that there was no statistically significant difference among the three sites for hydraulic conductivity, therefore, the average of 10 mm/h should be considered the hydraulic conductivity.

The overall analysis of variance F-test for differences in interrill erodibility coefficient was $F_{2,6}$ equal to 22.7 (p-value of 0.0016), therefore there was a statistically significant difference for the interrill erodibility coefficient. A Tukey's honestly significant difference (HSD) test indicated that the Long Walk site was statistically different at the 95% confidence interval from a group containing the Brush Creek and Summit sites.

Comparison to Road and Forest Infiltration

Figure 1 displays the combined hydrograph and sediment concentration graph for the Summit site. Note that during the first 30-minute storm, the runoff rate increased slowly and did not achieve a steady state runoff rate. Similarly, during the second storm the final runoff rate was still increasing. Only during the third storm did the runoff rate approach a steady-state value corresponding to 67% of the rainfall rate.

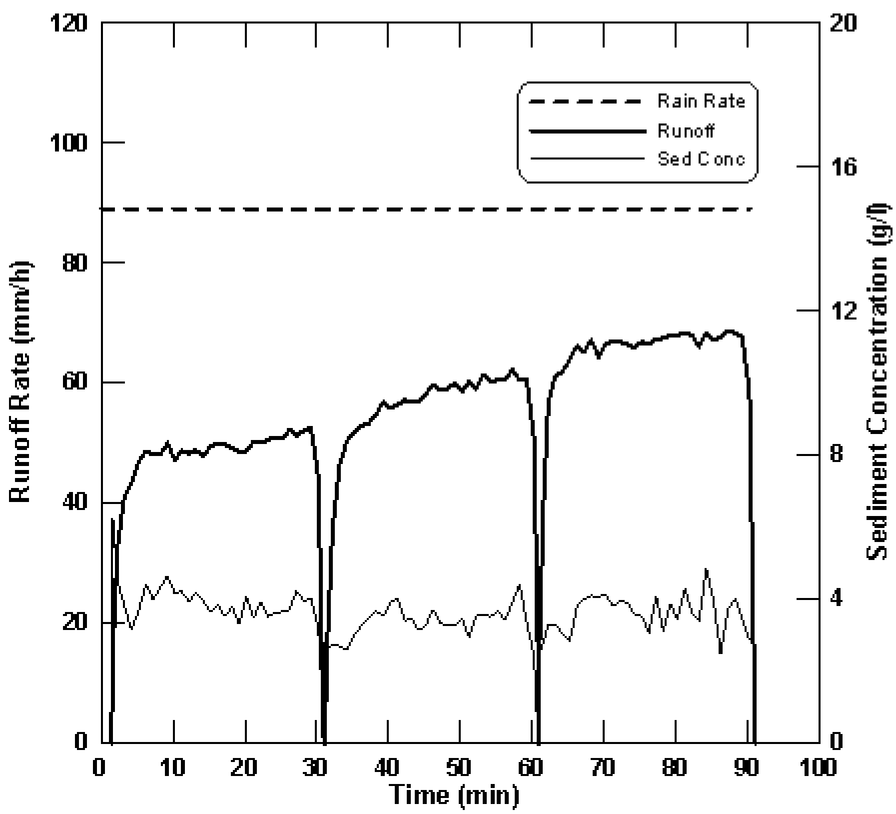

Figure 1 - Runoff and sediment concentration from obliterated road plot at the Summit site.

Figure 2 displays a combined hydrograph from a 1 m by 1 m plot located on a road surface constructed from decomposed granite parent material with a soil classification of gravelly loamy sand (Foltz, unpublished data). Immediately prior to the rainfall simulation the road was open to traffic which consisted of less than five light vehicles per day and no heavy truck traffic. The rainfall rate was 50 mm/hr, half that used on the obliterated road study. The differences between the two hydrographs are dramatic. Note that the runoff from the road surface rose very quickly (less than 2 minutes after rainfall starts) to a nearly constant value only slightly less than the rainfall rate. Subsequent storms follow the same pattern of a rapid rise after a few minutes to a runoff rate nearly equal to the applied rainfall rate. These are the characteristics of a low infiltration surface. WEPP model parameters of hydraulic conductivity and interrill erodibility coefficient for this site were 2 mm/h and 1.5 x 10 ^{6} kg s / m ^{4} , respectively. While no infiltration measurements were made prior to road obliteration at any of the three sites, the authors believe that all three sites would have had pre-obliteration runoff characteristics similar to those of Figure 2.

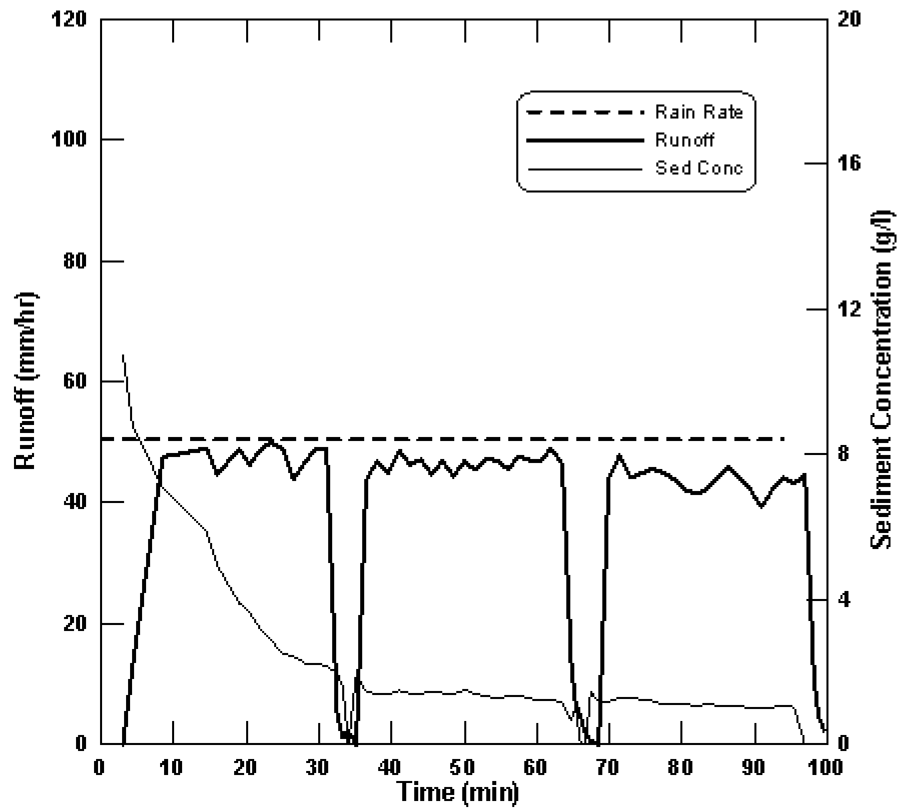

Figure 2 - Runoff and sediment concentration from road plot on decomposed granite site.

Figure 3 displays a combined hydrograph from a 1 m by 1 m plot located on an undisturbed forest floor in a weathered rhyolite parent material with a soil classification of gravelly loamy sand (Robichaud, 1996). The rainfall rate was 100 mm/hr, the same as the obliterated road study. This hydrograph reached a steady-state during the first storm in about 3 minutes after the start of runoff. Subsequent storms followed the same pattern. The steady-state runoff rates were about 10% of the applied rainfall rate. Robichaud reported that the hydraulic conductivity was 80 mm/h and the interrill erodibility coefficient was 0.24 x 10 ^{6} kg s / m ^{4} . These conditions represent what the obliterated road surface could achieve if full hydrologic function could be attained.

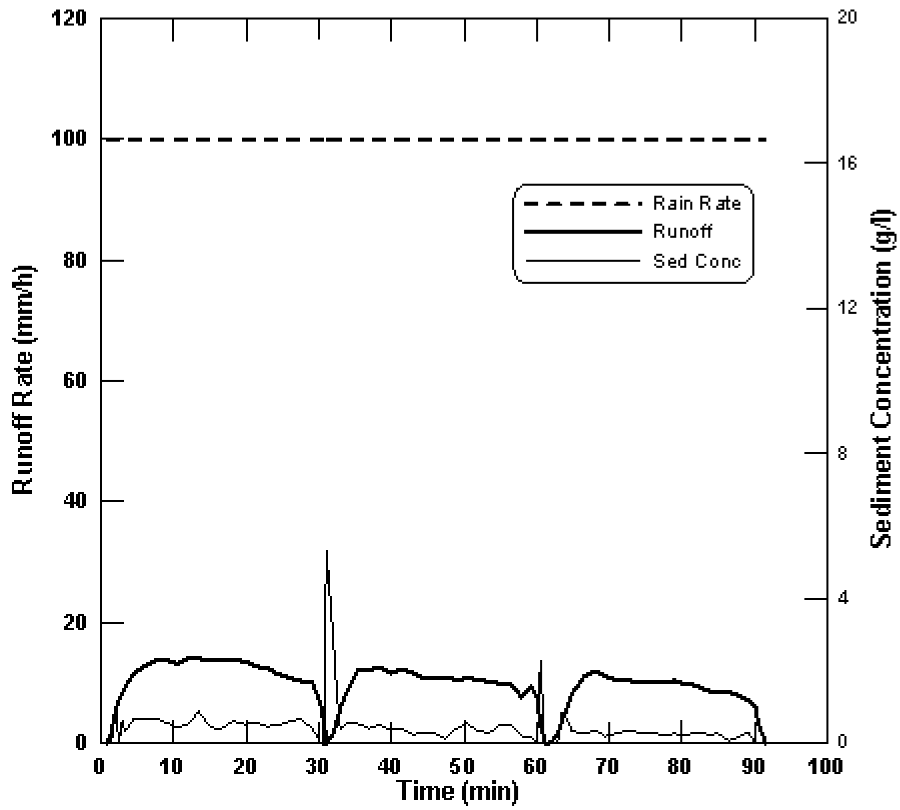

Figure 3 - Runoff and sediment concentration from forest floor plot. After Robichaud 1996.

Luce (1997) reported on an infiltration study on ripped roads. Road ripping is another road decommissioning technique that involves using heavy equipment to break up the road surface in an attempt to increase infiltration. From a granitic soil similar to the three obliteration sites, Luce reported that hydraulic conductivity immediately after ripping and prior to rainfall averaged 25 mm/h. Within three simulated rainfall events totaling approximately 75 mm, it had decreased to 7 mm/h. Surface sealing was the mechanism reported responsible for the decrease. Neither hydrographs nor erosion values were published.

Table 5 summarizes the infiltration and erosion characteristics of the road, ripped road, obliterated road, and forest discussed above. Both obliteration and ripping showed an improvement in infiltration compared to a road. The interrill erodibility coefficients for both the road and the obliterated road were an order of magnitude greater than the forest indicating elevated raindrop splash erosion compared to the forest.

Table 5. Summary of hydraulic conductivity and interrill erodibility coefficient.

	Hydraulic Conductivity (mm/h)	Interrill Erodibility Coefficient ($kg\ s / m^4$)
Road with light traffic [1]	2	1.5×10^6

Ripped road, after initial rainfall [2]	7	NA
Obliterated road, 2 to 3 years after obliteration [3]	10	2.5×10^{6}
Ripped road, immediately after ripping [2]	25	NA
Forest [4]	80	0.24×10^{6}

[1] - Foltz, unpublished data

[2] - Luce, 1997

[3] - This study

[4] - Robichaud, 1996

NA - Not Available

To investigate changes in the number of runoff producing events due to the road obliteration work, the WEPP model was run for a 30-year sequence of storms based on the climate at Deadwood Dam, ID located near the study area. A 1 square meter section of the road (2 mm/h), the obliterated road (10 mm/h) and the forest (80 mm/h) were simulated. Table 6 presents these results.

Table 6. Runoff summary from WEPP model for a 1 square meter section of road, obliterated road, and forest floor from 30-years of simulated climate.

	Rain	Snow		
	Runoff Producing Events	Mean Annual Runoff (mm)	Runoff Producing Events	Mean Annual Runoff (mm)
Road	99	15	232	65
Obliterated road	13	3	13	4
Forest	0	0	0	0

Although the increase in hydraulic conductivity after obliteration was modest (from 2 to 10 mm/h), it would provide a reduction in runoff events from both rainfall and snowmelt events. The number of rainfall events producing runoff decreased from an average of 3 events each year for the road to an average of 2 years between events for an obliterated road. The corresponding values for snowmelt events producing runoff were nearly 8 days of snowmelt runoff per year for the road to 2 years between events for the obliterated road. The reduction in events was largely due to the number of storm intensities greater than 2 mm/hr but less than 10 mm/hr. This range of intensities would produce runoff on the road, but not on the obliterated road. Although not demonstrated, the authors believe that similar reductions in runoff events would occur at other sites. It is noteworthy that the WEPP model did not predict any runoff from the forest for this 30-years of simulated storms.

This study represents a snapshot in time for infiltration and raindrop splash erosion. Freeze-thaw action over the time span of a few years would tend to increase infiltration. Ground cover increases due to regrowth would tend to decrease sediment production. Further information on how these processes impact erosion on a temporal scale at former stream crossings would be beneficial.

Conclusions

A study was performed to determine the infiltration and raindrop splash drop erosion characteristics at obliterated road crossings. Hydraulic conductivity averaged 10 mm/h at three sites that had been obliterated 2 to 3 years before the study. There was no statistically significant difference between the three sites. The average was above a typical road average of 2 mm/h, but substantially less than a typical forest floor of 80 mm/h. Even though the infiltration improvement was modest, it would be expected to reduce the number of runoff events due to rainfall from 3 each year to 2 years between events. The number of days with runoff due to snowmelt would be expected to decrease from 7 days each year to 2 years between events. These values were specific to the climate in McCall, ID where the study was performed. Changes at other locations would depend on the number of storms with precipitation intensities between 2 and 10 mm/h.

The interrill erodibility coefficient (raindrop splash) for the three obliterated roads fell into two statistically significant groups. One group had an average of 4.0×10^{6} while the other averaged 1.7×10^{6} kg m / s^{4}. Both of these groups were more similar to road than to forest floor conditions.

Vegetation regrowth and freeze thaw are two process that would change both the infiltration and raindrop splash erosion characteristics of former road-stream crossings. This study looked at the conditions after 2 to 3 years after obliteration. Further studies should be performed to investigate temporal changes.

Acknowledgements

The authors would like to acknowledge the hard work of several individuals. Foremost is Ben Kopyscianski of the Rocky Mountain Research Station in Moscow, ID who built the backpackable rainfall simulator and oversaw the field activities. Hakjun Rhee, a graduate student at the University of Washington, was a member of the field crew. Randy Zuniga, Jim Fitzgerald, and Tom Crawford of the Payette National Forest were instrumental in recognizing the need for the study, locating the research sites, and clearing the administrative hurdles to perform the simulations.

References

Alberts, E. E., M. A. Nearing, M. A. Weltz, L. M. Risse, F. B. Pierson, X. C. Zhang, J. M. Laflen, and J. R. Simanton. 1995. Soil Component. In *USDA - Water Erosion Prediction Project Hillslope Profile and Watershed Model Documentation* , 7.1 - 7.47. D. C. Flanagan and M. A. Nearing, eds. NSERL Report No. 10, USDA-ARS National Soil Erosion Research Laboratory, West Lafayette, IN.

Bosworth, D. 2003. Managing the National Forest System: Great Issues and Great Diversions. USDA Forest Service. Available at http://www.fs.fed.us/news/2003/speeches/great-issues-great-diversions.pdf. Accessed on 24 July 2003.

Coghlan, G., and R. Sowa. 1998. National Forest Road System and Use. USDA Forest Service. Available at http://www.fs.fed.us/eng/road_mgt/roadsummary.pdf. Accessed on 24 July 2003.

Flanagan, D. C. and S. J. Livingston (eds.). 1995. *WEPP User Summary* . NSERL Report No. 11, W. Lafayette, IN: National Soil Erosion Laboratory. 131 p.

Luce, C. H. 1997. Effectiveness of Road Ripping in Restoring Infiltration Capacity of Forest Roads. *Restoration Ecology* 5(3): 265-270.

Luce, C. H., and T. W. Cundy. 1994. Parameter Identification for a Runoff Model for Forest Roads. *Water Resources Research 30(4)* : 1057-1069.

Robichaud, P. R. 1996. Spatially-Varied Erosion Potential From Harvested Hillslopes After Prescribed Fire in the Interior Northwest. PhD diss. Moscow, ID. University of Idaho.

Stone, J. J., L. J. Lane, E. D. Shirley, and M. Hernandez. 1995. Hillslope Surface Hydrology. In *USDA - Water Erosion Prediction Project Hillslope Profile and Watershed Model Documentation* , 4.1 - 4.20. D. C. Flanagan and M. A. Nearing, eds. NSERL Report No. 10, USDA-ARS National Soil Erosion Research Laboratory, West Lafayette, IN.

Ward, T. J., and A. D. Seiger. 1983. Adaptation and Application of a Surface Erosion Model for New Mexico Forest Roadways. Technical Completion Report, Project Nos. 1423669 and 1345667. New Mexico State University, Las Cruces, NM.